Light Guide Plate Illumination with Blue Laser and Quantum Dot Emission

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Abstract

A Blue laser diode is used instead of LEDs to excite emission of Green and Red primaries from a strip of "quantum dot" materials at the edge of an LCD display light guide plate. Optical efficiency is improved by reflecting emission that would otherwise be lost. A phase randomizing deformable mirror is used to minimize speckle noise in the imagery.

1 Background

Laser diodes have certain characteristics which make them advantageous in comparison to LEDs for light guide plate illumination of direct view displays: their greater optical power means fewer sources are required and their lower étendue means efficient coupling into optical fiber is possible so that sources can be located somewhere other than the edge of the light guide plate. Red laser diodes have been used in addition to Green and Blue LEDs in the *Real LaserVue* series of LCD televisions commercialized by Mitsubishi Electric Corporation [1]. We have previously investigated the use of laser sources only for light guide plate illumination of a front-lit display [2]. Here we investigate the use of a use a Blue laser diode source to excite emission of Red and Green from a strip of quantum dot materials as shown in Figure 1.

The conventional arrangement to excite emission from a quantum dot strip using Blue LEDs is shown in Figure 2 [Top.] In the KDL-55W905A *Triluminos* LCD television commercialized by Sony Corporation, there are 72 LED modules distributed along the 680 mm quantum dot strips at each of the two shorter edges of the light guide plate. A heat sink with large surface area is located behind them. We propose two alternative arrangements enabled by laser diode illumination where a high reflectivity mirror is located behind the quantum dot strip to redirect emission which would otherwise not enter the light guide plate, see Figure 2 [Center, Bottom.]

Figure 1: Strip of quantum dot materials encapsulated in a glass tube, from QD Vision, Inc.

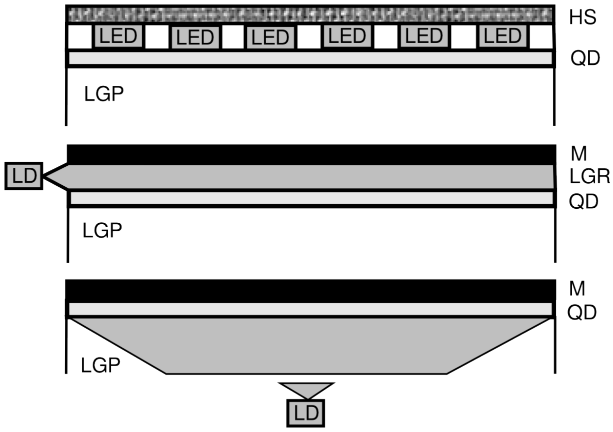

Figure 2: Arrangements for excitation of emission from quantum dot strip. Labels: LGP–light guide plate; QD–quantum dot strip; LD–laser diode; LED–light-emitting diode; LGR-light guide rod; M–mirror; HS–heat sink. [Top] Conventional LED arrangement. [Center] An essentially one-dimensional light guide is used to distribute the incident illumination along the quantum dot strip. [Bottom] Incident illumination is delivered through the light guide plate from a source coupled into the opposite edge.

2 Objectives

For both of the proposed arrangements we aim to measure the increase in brightness due to the use of the mirror behind the quantum dot strip. The problem of speckle [3], which can seriously degrade image quality when using coherent illumination, is also considered. We aim to observe any speckle arising and to investigate its elimination using Dyoptyka's phase randomizing deformable mirror, see Figure 5 [Center.]

3 Apparatus

We used the quantum dot strips from a Sony KDL-55W905A and a Nichia NDB7875 445 nm blue laser diode with up to 1.2 W optical power, as shown in Figures 1 and 5 respectively.

For incident illumination through the light guide rod, we used the arrangement shown in Figure 3 [Top right] which was convenient for laboratory assembly. Figure 3 [Bottom] shows that it is effective at exciting emission from the quantum dot strip. The incident illumination was focused into the light guide rod at on the left side and it can be seen that some exits the rod on the right side. In an optimized setup an additional mirror could be located at the exit face.

For incident illumination through the light guide plate, we adjusted the focusing lens so that the divergence of the fast axis matched the quantum dot strip length.

We arranged the diffuser sheets from the Sony KDL-55W905A above and below a transparent PMMA light guide plate of 3 mm thickness, covered with diffusing adhesive tape on the output side, and cut to a size convenient for laboratory experimentation, as shown in Figure 4 [Top.]

For reduction of speckle in the imagery we used a Dyoptyka uDM2 deformable mirror, as shown in Figure 5 [Center,] located between the laser diode and a focusing lens. For further investigation of speckle we operated the laser diode at two different drive currents: 200 mA for essentially single mode, highly coherent emission and 1000 mA for multimode emission of significantly less coherence.

The camera imaging parameters were chosen such that speckle in the acquired imagery was considered subjectively to be similar what was perceived by observers: lens focal length f=50 mm, aperture stop $f/16$, and magnification approximately 4×.

4 Results

Figures 6 and 7 show how image brightness is improved significantly when a mirror is positioned behind the quantum dot strip in both of the proposed illumination configurations.[1]

Figures 8 and 9 show how image quality is unacceptable due to speckle and how it can be greatly improved through the action of the deformable mirror. They also show how speckle is reduced due to less coherent illumination at higher laser power. However one interesting characteristic of speckle is that its size grows proportionally to the distance of observation so although it is not significant in the imagery presented, it is much worse when viewed from several meters.

[1] Note that the brightness difference between the two proposed illumination configurations is due to the way we arranged the apparatus rather than to any fundamental difference in performance between the configurations.

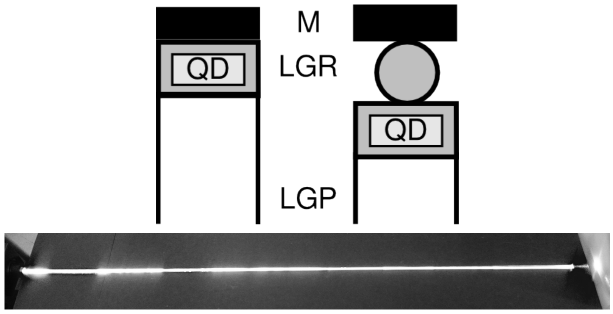

Figure 3: [Top left] An arrangement where light guide for incident illumination allows some to couple directly into the light guide plate. [Top right] Arrangement used for experimentation. Transparent optical adhesive was used to bond a 2 mm diameter fused quartz rod to the glass tube encapsulating the strip quantum dot materials. [Bottom] Emission from the 680 mm strip illuminated through the light guide rod. Inhomogeneity of emission may be due to uneven distribution of adhesive and some segments of the quantum dot materials not touching the encapsulating tube.

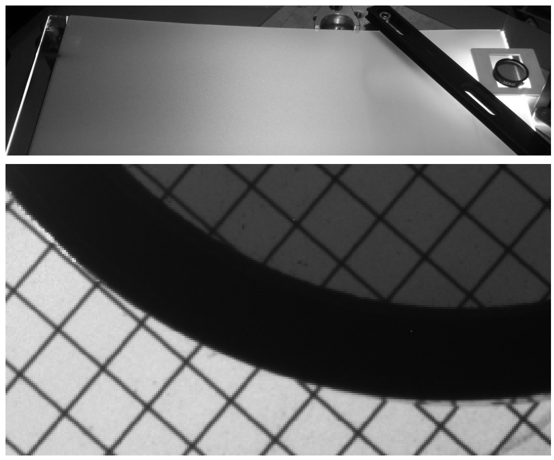

Figure 4: [Top] Apparatus showing light guide plate with some illumination exiting the edge opposite the incident side, diffuser sheets, clamp, pattern slide, and 437–447 nm bandpass filter. [Bottom] Image from camera mounted directly above pattern slide and bandpass filter. Side length of squares is 1.25 mm.

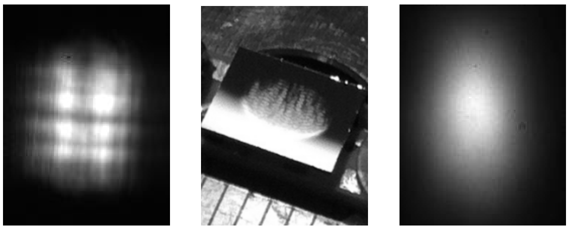

Figure 5: [Left] Multimode emission from Nichia NDB7875 445 nm blue laser diode. [Center] Dyoptyka uDM2 miniaturized deformable mirror with fully integrated 5 V control electronics. Elliptical area of 3.0 mm by 4.5 mm is actuated at hundreds of kHz resulting in randomly-distributed surface deformations which achieve effective inter-modal dispersion in light guides and the generation of uncorrelated speckle patterns. [Right] Multimode emission dynamically redistributed by uDM2 and focused to a spot of the same size as original.

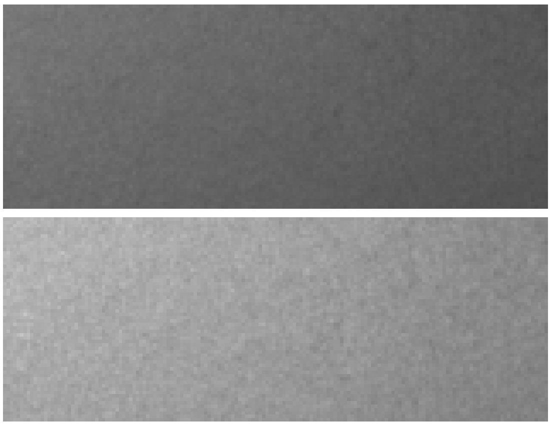

Figure 6: Area of diffuser sheet near quantum dot strip illuminated through the LGP. [Top] Without mirror behind strip, mean pixel intensity is 99 (of 255 maximum,) range is 76–126, standard deviation is 9. [Bottom] With mirror behind strip, mean pixel intensity is 155, range is 120–198, standard deviation is 14. This is nearly 60% brighter than without the mirror.

5 Conclusions

We have demonstrated excitation of emission from quantum dot materials using a laser diode. Improved brightness was achieved and speckle noise in the image was effectively reduced.

The main benefits arising include: (1) a small number of powerful and energy efficient laser diode sources can be used to illuminate direct view displays without a perceptible speckle problem arising; (2) the laser diodes do not need to be at the edge of the light guide plate. They could be located elsewhere, with optimized heat-sinking, and the illumination

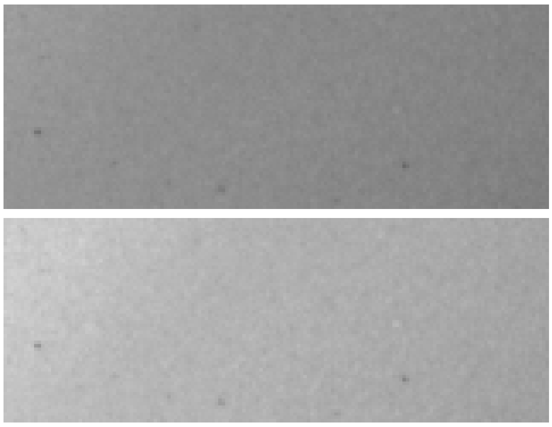

Figure 7: Area of diffuser sheet near quantum dot strip illuminated through the LGR. Note that the incident laser power is different to the LGP illumination. [Top] Without mirror behind LGR, mean pixel intensity is 138 (of 255 maximum,) range is 99–162, standard deviation is 7. [Bottom] With mirror behind LGR, mean pixel intensity is 175, range is 127–212, standard deviation is 11. This is nearly 30% brighter than without the mirror.

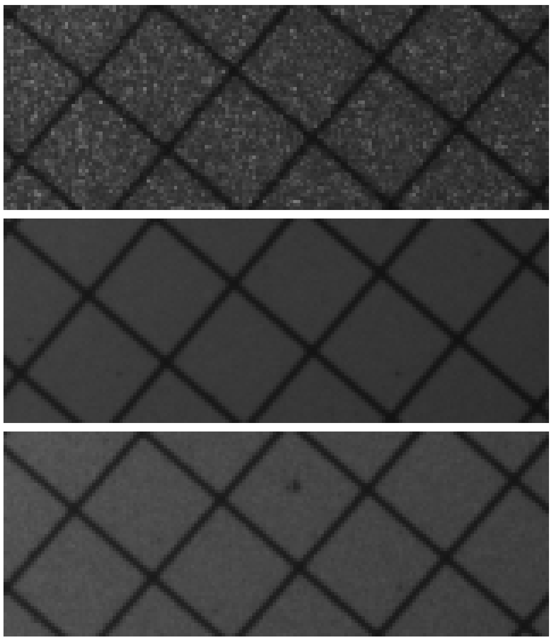

Figure 8: Illumination through LGP: area of diffuser sheet with pattern slide viewed through Blue bandpass filter. [Top] Single mode illumination and deformable mirror inactive, speckle pattern is easily visible. [Middle] Single mode illumination and deformable mirror active, speckle pattern is not visible. [Bottom] Multimode illumination and deformable mirror inactive, speckle pattern is greatly reduced.

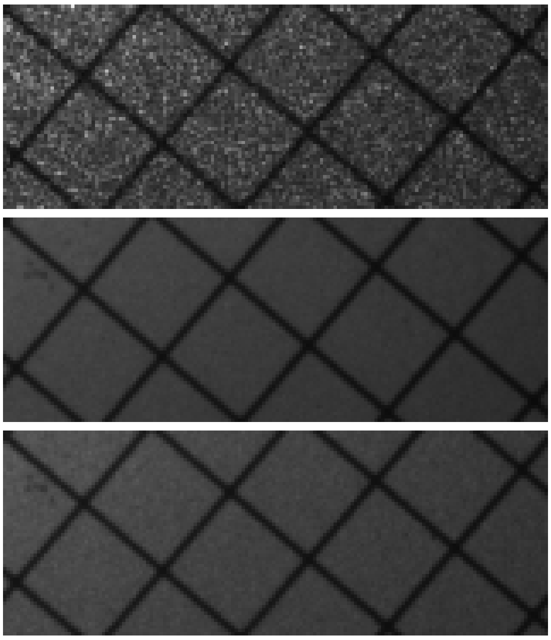

Figure 9: Illumination through LGR: area of diffuser sheet with pattern slide viewed through Blue bandpass filter. [Top] Single mode illumination and deformable mirror inactive, speckle pattern is easily visible. [Middle] Single mode illumination and deformable mirror active, speckle pattern is not visible. [Bottom] Multimode illumination and deformable mirror inactive, speckle pattern is greatly reduced.

delivered efficiently through optical fiber or another kind of light guide; (3) loss of emission from quantum dot strips can be reduced using a mirror located where LEDs would otherwise need to be located.

It should be noted that benefits (1) and (2) also apply to displays using a sheet of quantum dot materials covering the surface of the light guide plate.

References

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